Observationally Closing the Arctic Atmosphere-Surface Energy Budget (SEB)

Subtext 1: Can it be done?

Subtext 2: The Science of Observations

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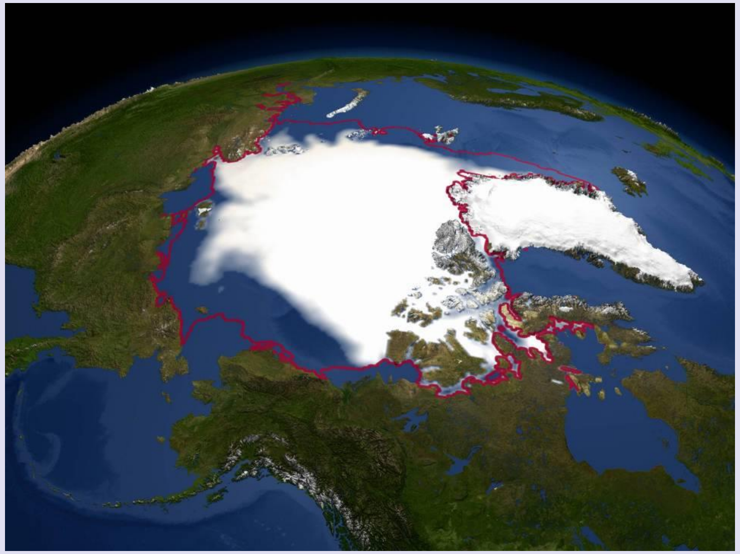
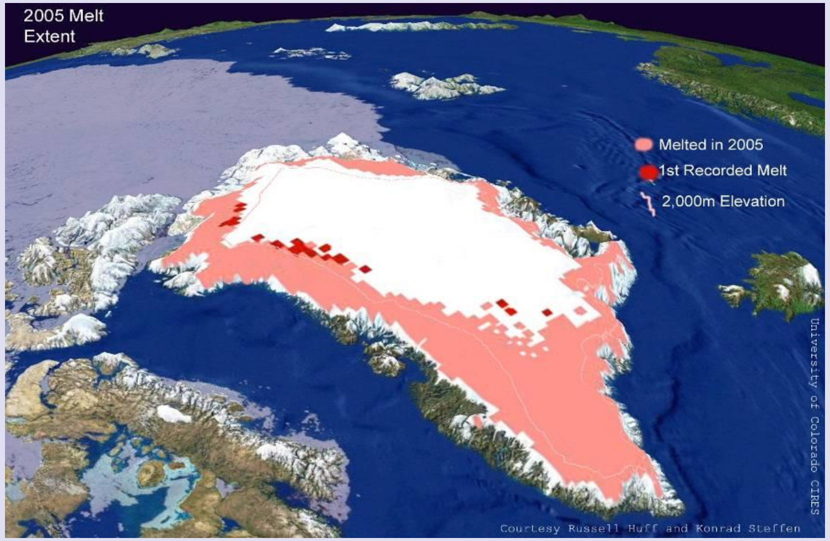
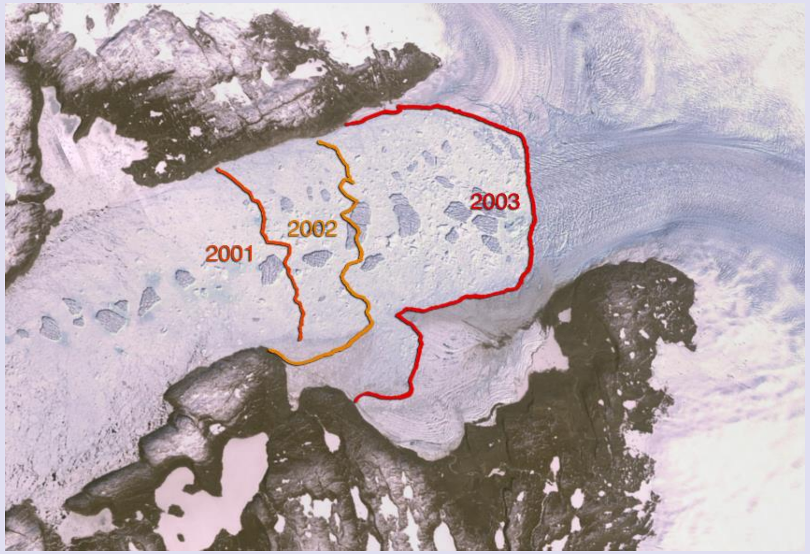
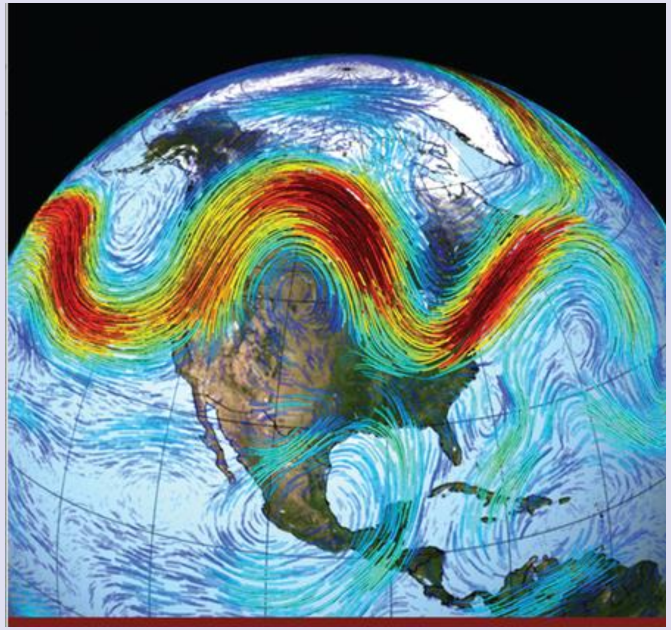
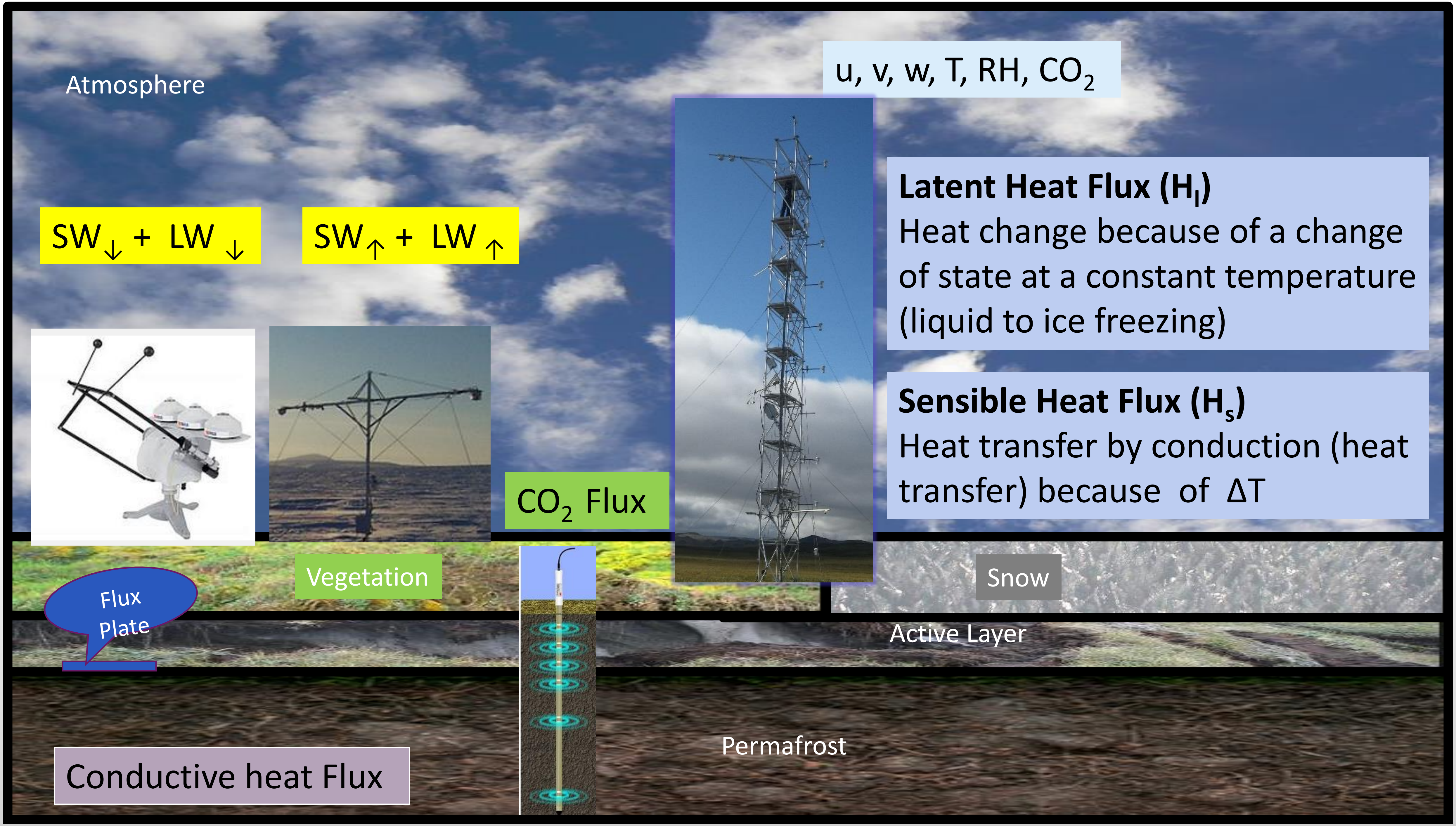
Why the SEB is important:



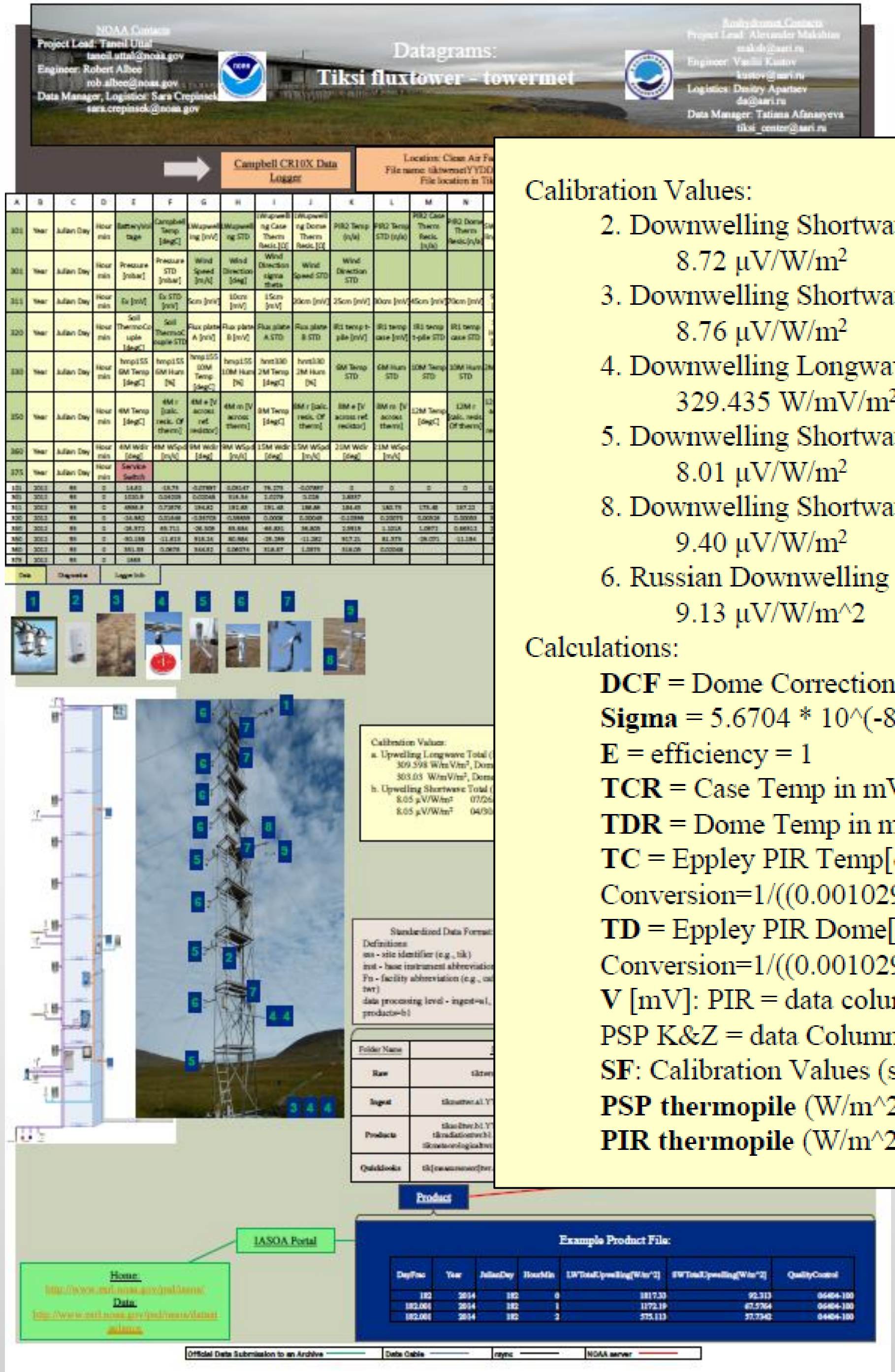


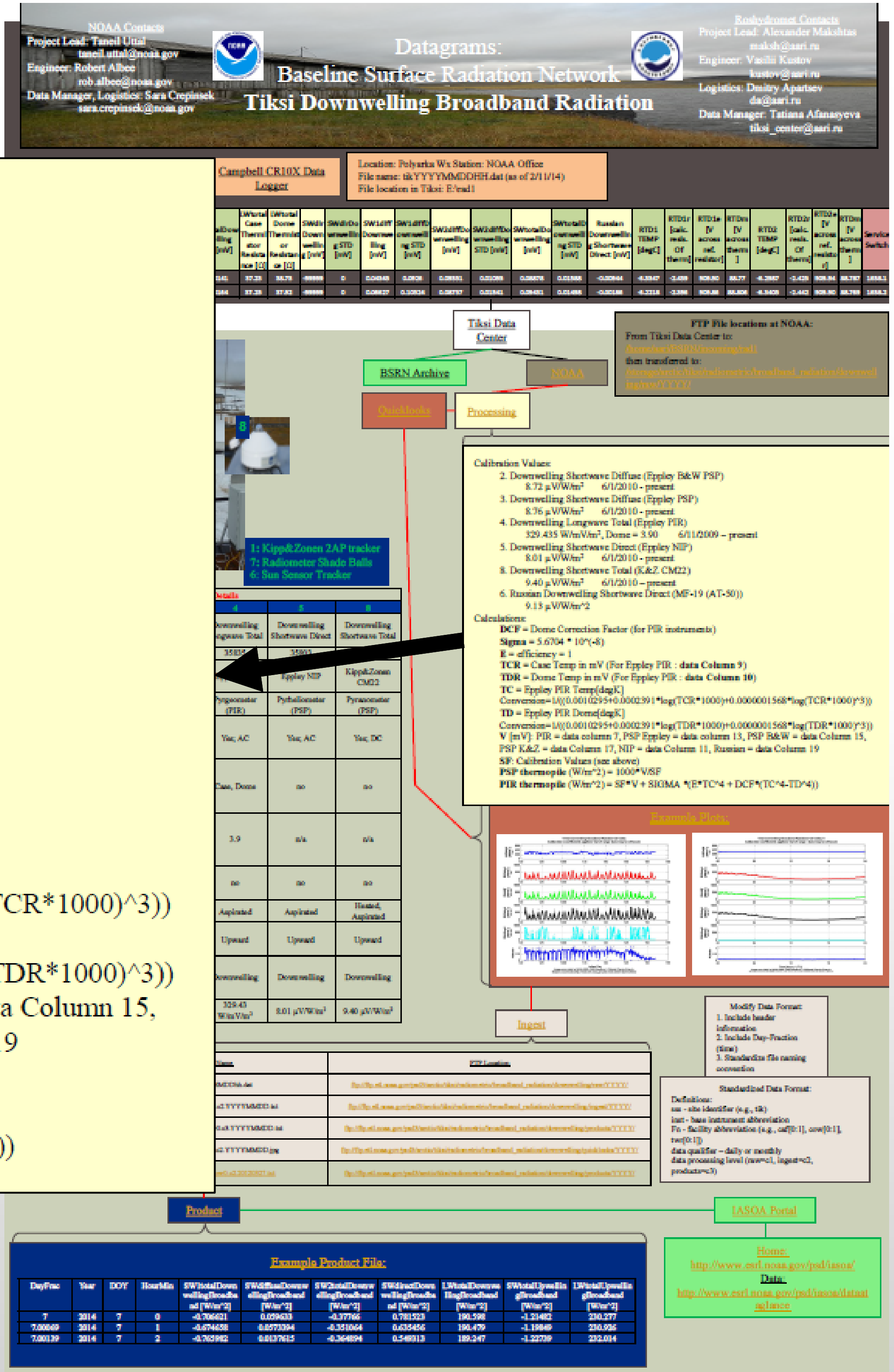





Atmosphere
u, v, w, T, RH, CO_2
$SW_{\downarrow}$ + $LW_{\downarrow}$
$SW_{\uparrow}$ + $LW_{\uparrow}$
Latent Heat Flux (H_l)
Heat change because of a change of state at a constant temperature (liquid to ice freezing)
Sensible Heat Flux (H_s)
Heat transfer by conduction (heat transfer) because of ΔT
CO_2 Flux
Vegetation
Snow
Flux Plate
Active Layer
Permafrost
Conductive heat Flux

Datagrams





Calibration Values:

2. Downwelling Shortwave Diffuse (Eppley B&W PSP)
   8.72 µV/W/m² 6/1/2010 - present
3. Downwelling Shortwave Diffuse (Eppley PSP)
   8.76 µV/W/m² 6/1/2010 - present
4. Downwelling Longwave Total (Eppley PIR)
   329.435 W/mV/m², Dome = 3.90 6/11/2009 – present
5. Downwelling Shortwave Direct (Eppley NIP)
   8.01 µV/W/m² 6/1/2010 - present
8. Downwelling Shortwave Total (K&Z CM22)
   9.40 µV/W/m² 6/1/2010 – present
6. Russian Downwelling Shortwave Direct (MF-19 (AT-50))
   9.13 µV/W/m^2

Calculations:

DCF = Dome Correction Factor (for PIR instruments)

Sigma = 5.6704 * 10^(-8)

E = efficiency = 1

TCR = Case Temp in mV (For Eppley PIR : **data Column 9**)

TDR = Dome Temp in mV (For Eppley PIR : **data Column 10**)

TC = Eppley PIR Temp[degK]

Conversion=1/((0.0010295+0.0002391*log(TCR*1000)+0.0000001568*log(TCR*1000)^3))

TD = Eppley PIR Dome[degK]

Conversion=1/((0.0010295+0.0002391*log(TDR*1000)+0.0000001568*log(TDR*1000)^3))

V [mV]: PIR = data column 7, PSP Eppley = data column 13, PSP B&W = data Column 15, PSP K&Z = data Column 17, NIP = data Column 11, Russian = data Column 19

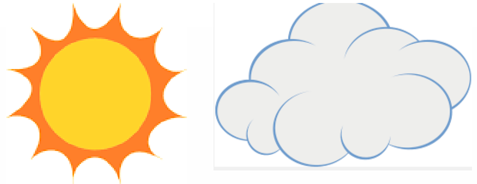
SF: Calibration Values (see above)

PSP thermopile (W/m^2) = 1000*V/SF

PIR thermopile (W/m^2) = SF*V + SIGMA *(E*TC^4 + DCF*(TC^4-TD^4))

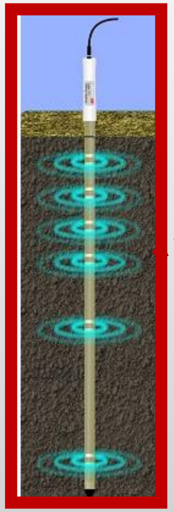
$$\underbrace{(SW_{net} + LW_{net})}_{\text{Radiation Fluxes}} + \underbrace{(Q_s + Q_l)}_{\text{Turbulent Fluxes}} + \underbrace{G}_{\text{Ground Flux}} = R \text{ (residual)}$$

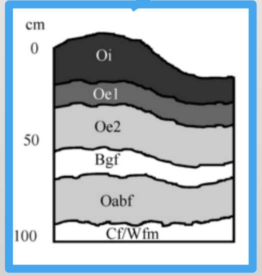
Measuring the Arctic Atmosphere-Surface Energy Balance



Measured
Working on it
Need additional obs

$$SW\downarrow + LW\downarrow + \langle Q_s\uparrow\downarrow + Q_l\uparrow\downarrow\rangle_\mu + S_{RFD}\uparrow\downarrow + \langle Q_s\uparrow\downarrow + Q_l\uparrow\downarrow\rangle_M +$$
$$G\uparrow\downarrow + S_G\uparrow\downarrow + SW\uparrow\downarrow + LW\uparrow + S_P\uparrow\downarrow + S_C\uparrow\downarrow + S_S\uparrow\downarrow \overset{?}{=} 0$$





SW = Short Wave
LW = Long Wave
Q = Turbulent Fluxes
Subscripts:
s= sensible heat
l = latent heat
μ = microscale
M = mesoscale
G = Soil
S = Storage Terms
Subscripts:
RFD = Radiative Flux Divergence
G = Soil
P = Photosynthesis
C = Canopy temp
S = Snow
↑ = cooling
↓ = warming

$Q_G = G\uparrow\downarrow + S_G\uparrow\downarrow$

Ground Flux

$$\underbrace{Q_G}_{\text{Ground Flux}} = \underbrace{-\lambda_s \frac{\Delta T}{\Delta z}}_{\text{Conductive Flux}} \underbrace{- C_s \frac{\Delta T}{\Delta t}\Delta z}_{\text{Storage Term}}$$

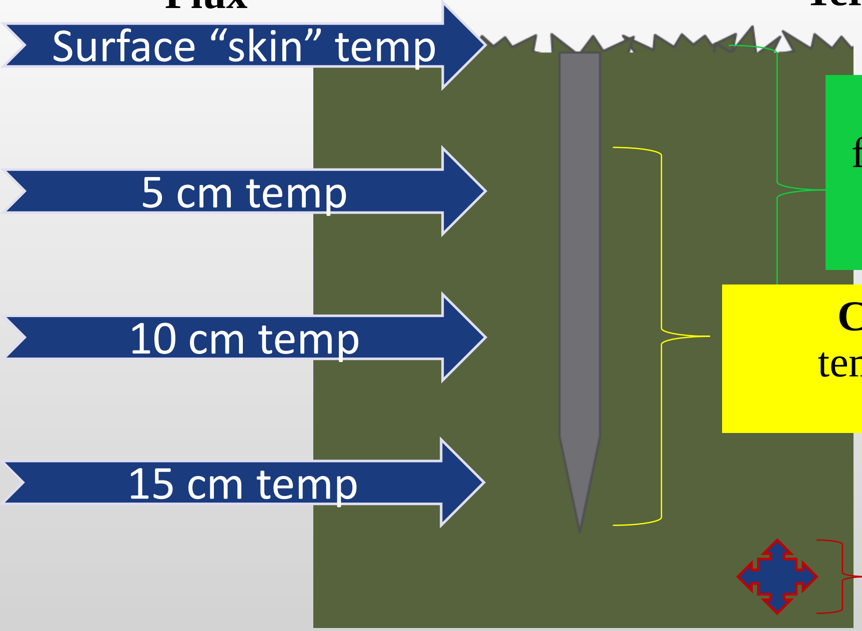
1. Flux Plate instruments

$$Q_G = \underbrace{G\uparrow\downarrow}_{\text{Direct Flux}} + \underbrace{C_s\left(\frac{T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{2(t_{n+1} - t_{n-1})}\right)(z_{05} - z_{sfc})}_{\text{Storage Term}}$$

2. Thermistor instruments

$$Q_G = \underbrace{-\lambda_s\left(\frac{T_{05}^{n} - T_{15}^{n}}{z_{05} - z_{15}}\right)}_{\text{Direct Flux}} + \underbrace{C_s\left(\frac{T_{10}^{n+1} - T_{10}^{n-1} + T_{05}^{n+1} - T_{05}^{n-1} + T_{sfc}^{n+1} - T_{sfc}^{n-1}}{3(t_{n+1} - t_{n-1})}\right)(z_{10} - z_{sfc})}_{\text{Storage Term}}$$

Issue: Accurate measurements of C_s (soil heat capacity) and λ_s (soil conductivity)



Storage Term: accounting for any stored energy in layer near surface layer above the highest T measurement

Conductive Flux: temperature gradient measurements

Soil Constants:

soil thermal conductivity, soil heat capacity

$Q_s \uparrow\downarrow + Q_l \uparrow\downarrow$ (μ) (M) Turbulent Fluxes

Calculations with eddy covariance methods

$$\tau = -\rho < w'u' >$$

$$H_S = \rho C_P < w'\theta' >$$

$$H_L = \rho L < w'q' >$$

- Double axis rotation for sonic anemometer tilt correction
- Linear detrending of raw time series (*Kaimal and Finnigan, 1994*)
- Compensation for air density fluctuations (*Webb et al., 1980)*
- Statistical tests for raw time series data (*Vickers and Mahrt, 1997*)
    - *Spike count/removal (Mauder et al., 2013)*
    - *Amplitude resolution*
    - *Dropouts*
    - *Absolute limits*
    - *Skewness and kurtosis*
    - Angle of attack
    - Steadiness of horizontal wind

Issue: Continuity of methodology and large scale advection fluxes

Estimates with gradient and bulk methods

$$\tau = \rho K_M (\partial \bar{u} / \partial z)$$

$$H_S = -\rho C_P K_H (\partial \bar{\theta} / \partial z)$$

$$H_L = -\rho L K_W (\partial \bar{q} / \partial z)$$

where according to Monin - Obukhov Similarity Theory

$$K_M = k u_* (z - d) / \phi_m(\zeta)$$

$$K_H = k u_* (z - d) / \phi_h(\zeta)$$

$$K_W = k u_* (z - d) / \phi_w(\zeta)$$

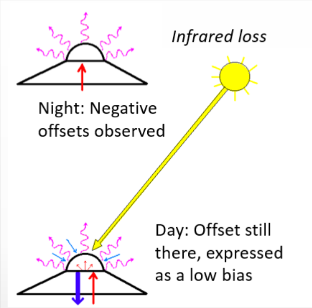
- Fluxes are driven by gradients in u, T, and q
- Fluxes are proportional to friction velocity
- These are simply definitions of KM, KH, KW
- Ohm’s Law combined with Similarity

SW↓ + LW↓ + SW↑↓ + LW↑ Radiation Fluxes

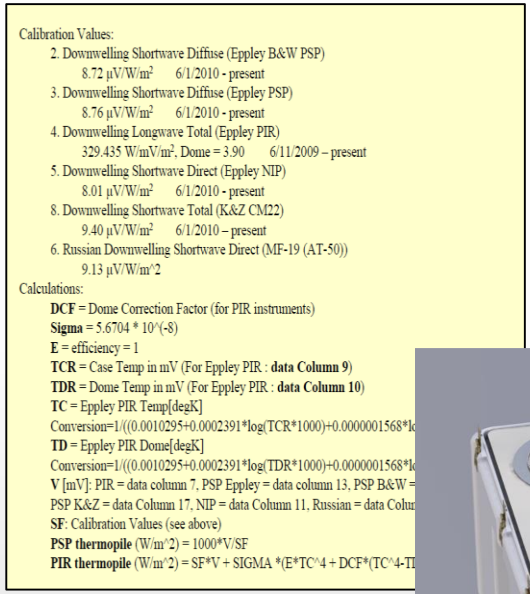
SWD (K-Z CM22), DIFFUSE (Eppley PSP), DIRECT (Eppley (NIP), SWU (Eppley PSP), LWD/LWU (Eppley PIR)

Quality Control - QCRAD" (Long and Shi 2008)

- "Uses fluxes, 2m temperature, 2m RH (common to all BSRN stations). Primary assumption is that most of the data is "good".
- Physically possible limits, climatological configurable limits based on relationships between variables.
- Applies correction for IR loss in shortwave measurements (Shi and Long 2007)
- SWD is combination of DIR+DIFF ("SUM") and GLOBAL: SUM whenever available.



CALIBRATION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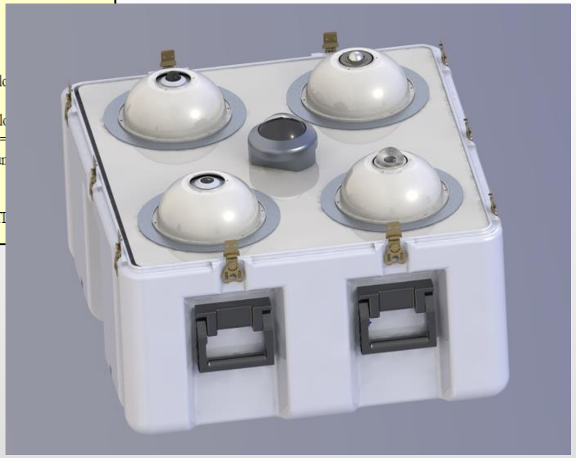


ICING

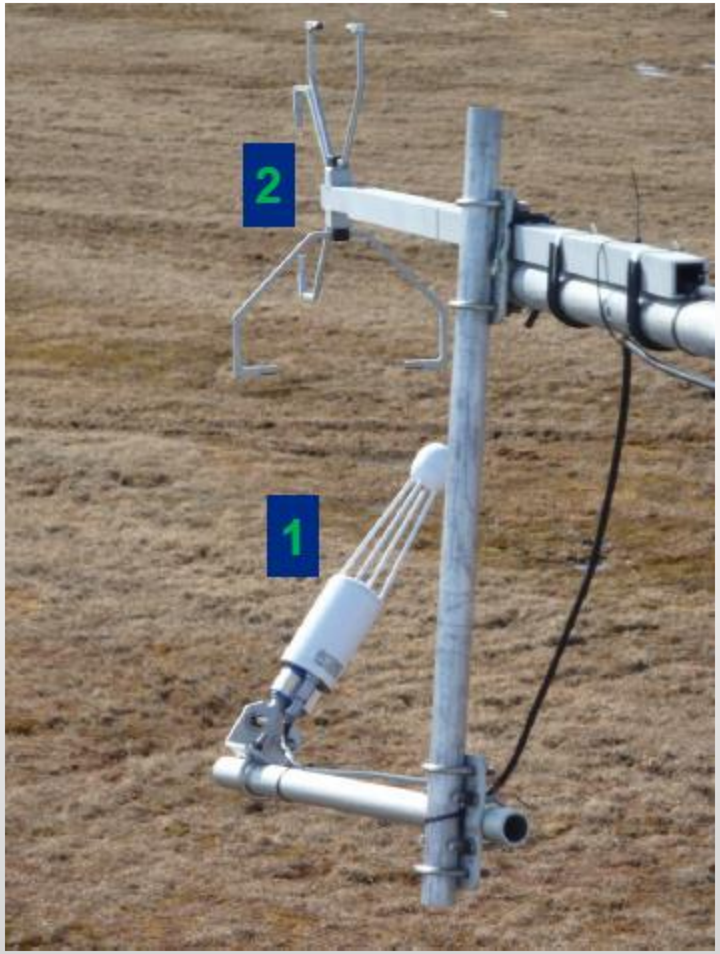
Issues: quality control, calibration and icing

S_P ↑↓ + S_C↑↓ Vegetation Fluxes and Storage

How much energy is stored by photosynthesis? 479 kJ of energy is stored per mole of CO_2 fixed into photosynthetic products. For example, a canopy assimilation rate of 10 [\mu mol/m^2 s] equates to energy flux of 4.79 ~ 5 [W/m^2]. The photosynthesis storage term (as well as the storage term because of changes in leaf temperature) is relatively small but important for understanding impacts of the changing climate on the ecosystem.

- (Nobel P.S. (1991) "Physicochemical and Environmental Plant Physiology" (Chapter 7.1, page 321)

Issue: need better integration with ecosystem colleagues

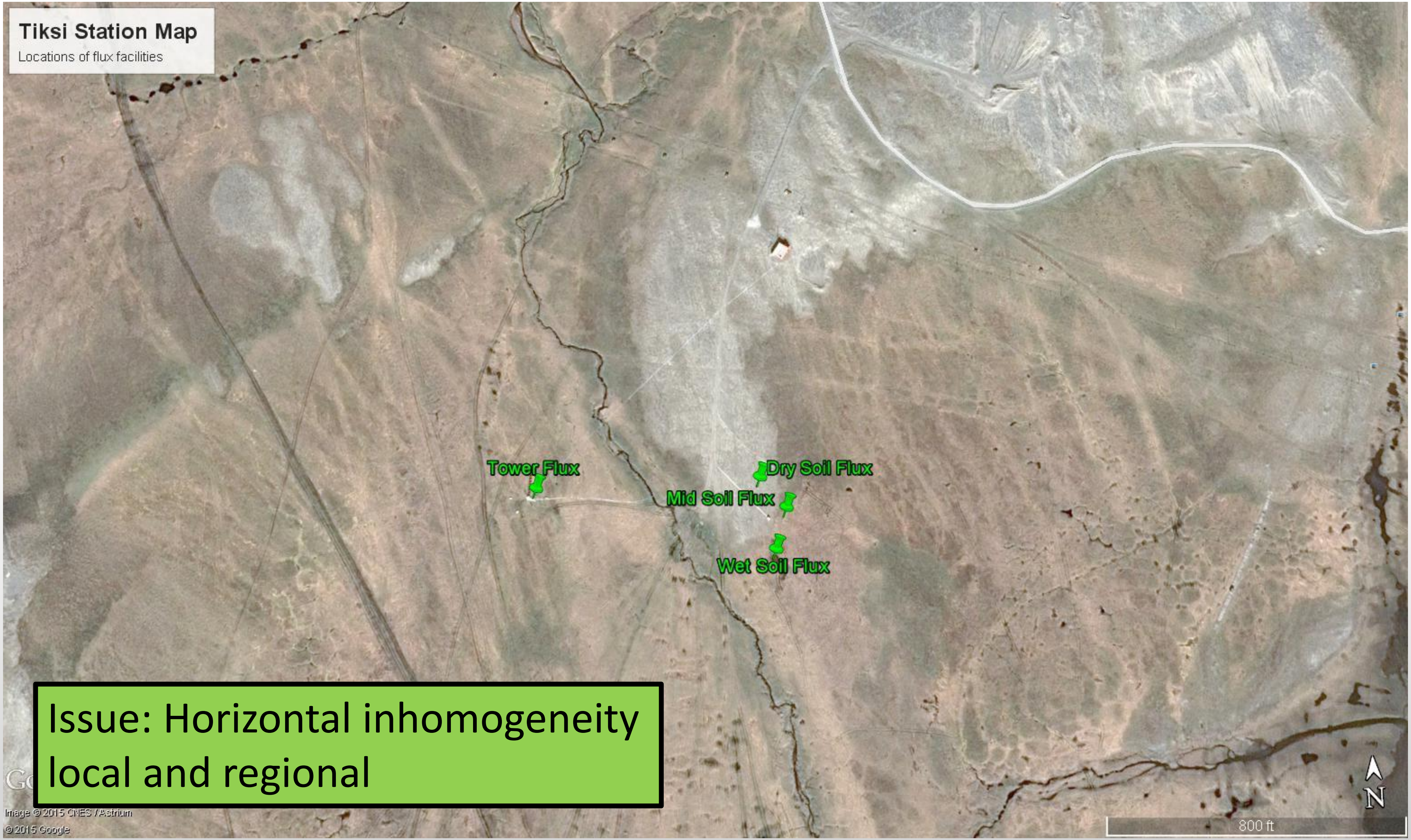


S_s ↑↓

Snow Fluxes and Storage

- Storage through freeze/melt processes
- Snow chemistry as a source sink of CO2 Fluxes

Issue: need better integration with snow physicists



Issue: Horizontal inhomogeneity local and regional

Specialist: Ground Flux and Storage

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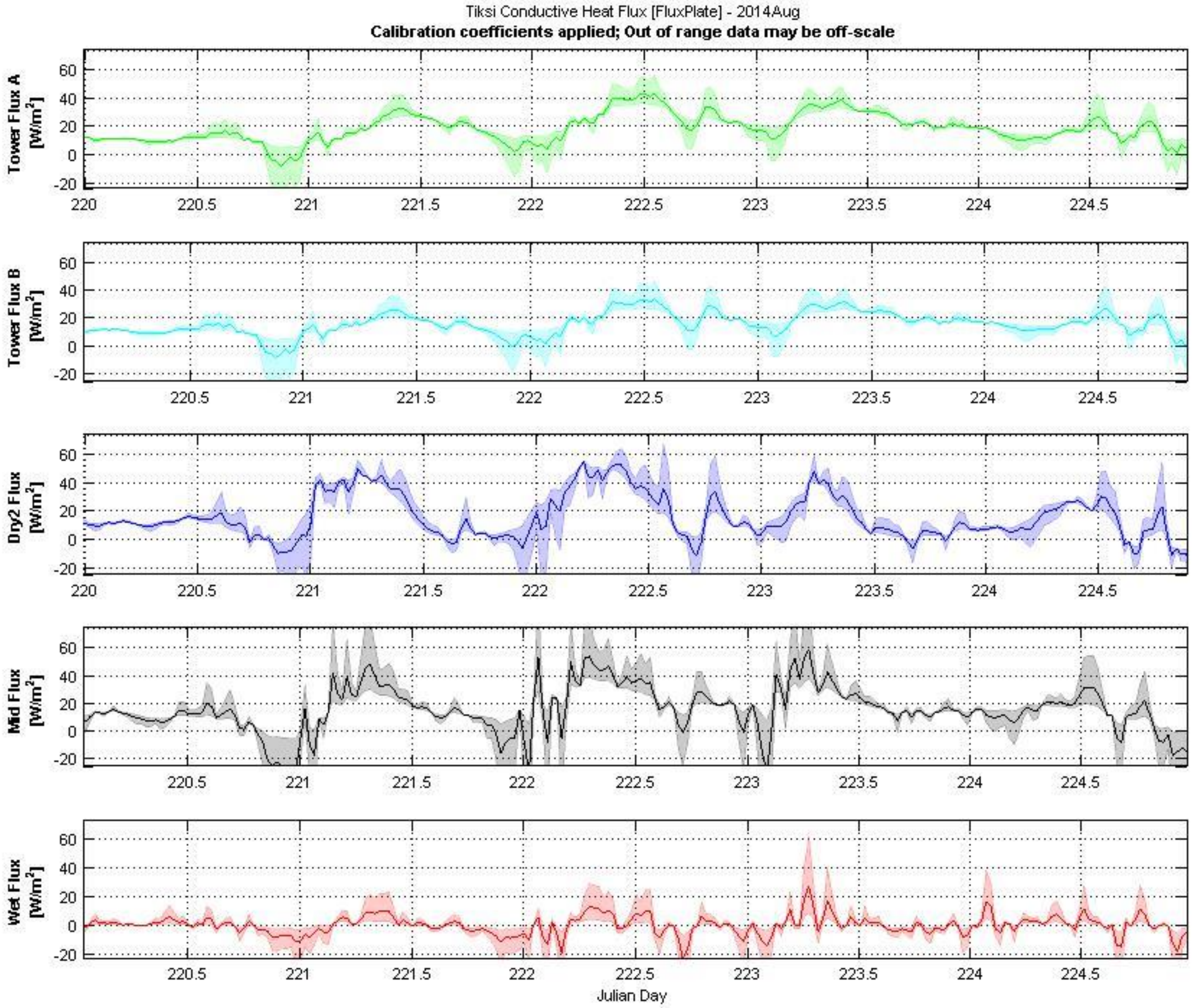
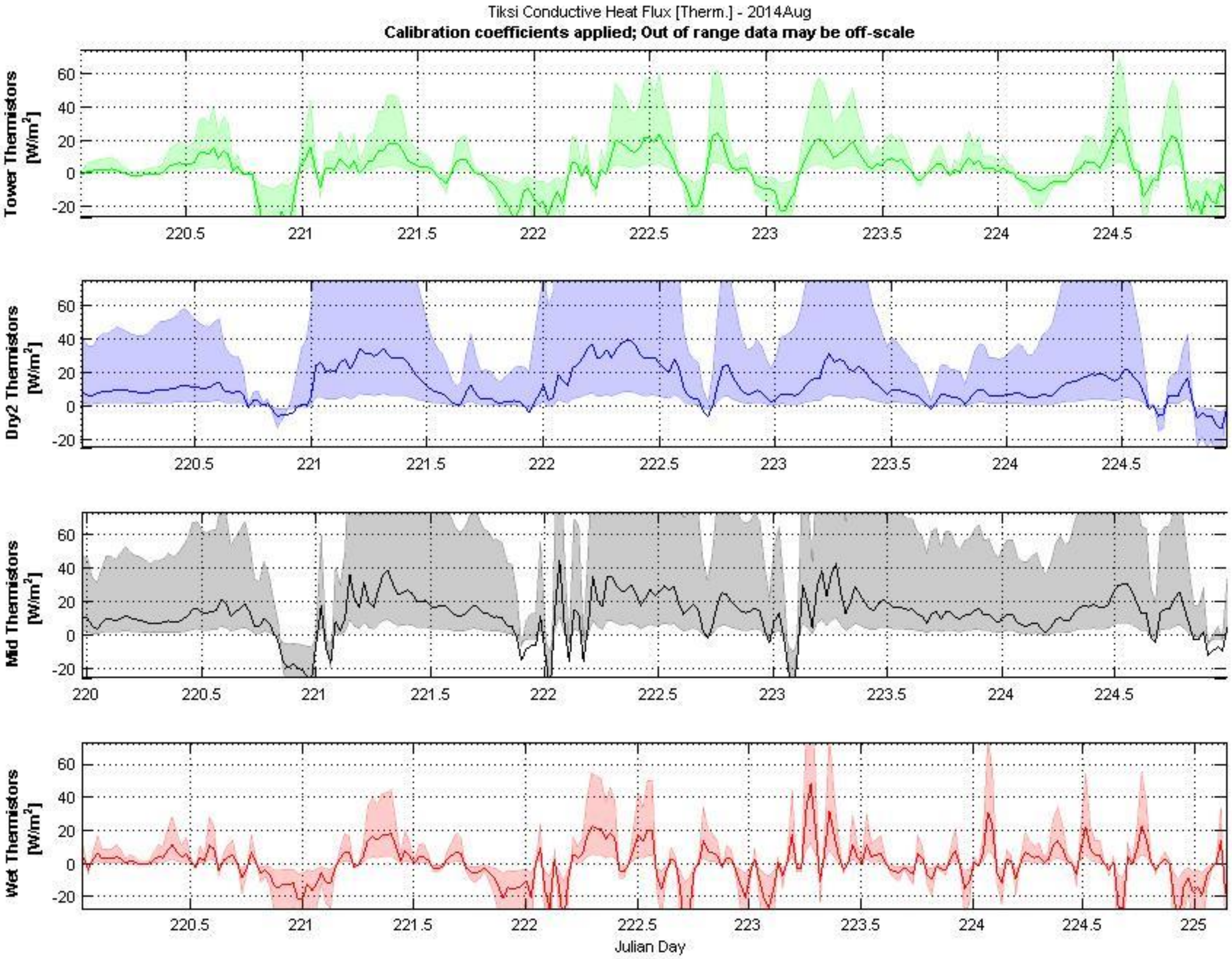
Site Description	Thermal Conductivity [ ]	Thermal Conductivity Conversion	Heat Capacity [C]	Heat Capacity Conversion	Author/Paper
West Dock	0.60 Wm-1K-1	0.60 Wm-1K-1	2.70 MJm-3K-1	2.70 MJm-3K-1	Romanovsky & Osterkamp, 1997
Deadhorse	0.77 Wm-1K-1	0.77 Wm-1K-1	2.36 MJm-3K-1	2.36 MJm-3K-1	Romanovsky & Osterkamp, 1997
Franklin Bluffs	0.82 Wm-1K-1	0.82 Wm-1K-1	2.30 MJm-3K-1	2.30 MJm-3K-1	Romanovsky & Osterkamp, 1997
Quartz	0.021 cal cm-1 sec-1 celsius-1	8.792276 Wm-1K-1			Sellers, 1965
Clay minerals	0.007 cal cm-1 sec-1 celsius-1	2.930759 Wm-1K-1			Sellers, 1965
Organic matter	0.0006 cal cm-1 sec-1 celsius-1	0.2512079 Wm-1K-1			Sellers, 1965
Water	0.00137 cal cm-1 sec-1 celsius-1	0.5735914 Wm-1K-1			Sellers, 1965
Ice	0.0052 cal cm-1 sec-1 celsius-1	2.177135 Wm-1K-1			Sellers, 1965
Air	0.00006 cal cm-1 sec-1 celsius-1	0.02512079 Wm-1K-1			Sellers, 1965
Quartz	8.4 Wm-1K-1	8.4 Wm-1K-1	1942 Jm-3K-1	1.942 MJm-3K-1	Peters-Lidard et al., 1997
Soil minerals	2.9 Wm-1K-1	2.9 Wm-1K-1	1942 Jm-3K-1	1.942 MJm-3K-1	Peters-Lidard et al., 1997
Soil organics	0.25 Wm-1K-1	0.25 Wm-1K-1	2503 Jm-3K-1	2.503 MJm-3K-1	Peters-Lidard et al., 1997
Water	0.6 Wm-1K-1	0.6 Wm-1K-1	4186 Jm-3K-1	4.186 MJm-3K-1	Peters-Lidard et al., 1997
Ice	2.5 Wm-1K-1	2.5 Wm-1K-1	1883 Jm-3K-1	1.883 MJm-3K-1	Peters-Lidard et al., 1997
Air	0.026 Wm-1K-1	0.026 Wm-1K-1	1.20 Jm-3K-1	0.0012 MJm-3K-1	Peters-Lidard et al., 1997
Mineral-organic mixture	[0.7, 1.8] Wm-1K-1	[0.7, 1.8] Wm-1K-1			Permafrost Laboratory
Mineral-soil(silt)	[1.3, 2.4] Wm-1K-1	[1.3, 2.4] Wm-1K-1			Permafrost Laboratory
Mineral-Soil(gravel)	[2.5, 3.5] Wm-1K-1	[2.5, 3.5] Wm-1K-1			Permafrost Laboratory
Mineral-Soil(Shale)	[1.0, 2.0] Wm-1K-1	[1.0, 2.0] Wm-1K-1			Permafrost Laboratory
Quartz	8.4 Wm-1K-1	8.4 Wm-1K-1			Farouki, 1981
Soil minerals	2.9 Wm-1K-1	2.9 Wm-1K-1			Farouki, 1981
Soil organics matter	0.25 Wm-1K-1	0.25 Wm-1K-1			Farouki, 1981
Water	0.6 Wm-1K-1	0.6 Wm-1K-1			Farouki, 1981
Air	0.026 Wm-1K-1	0.026 Wm-1K-1			Farouki, 1981
Ice (temp -20 degC)	0.00581 cal cm-1 sec -1 celsius-1	2.43253 Wm-1K-1			Farouki, 1981
Ice (temp -20 degC)	0.00545 cal cm-1 sec -1 celsius-1	2.281805 Wm-1K-1			Farouki, 1981
Ice (temp 0 degC)	0.00535 cal cm-1 sec -1 celsius-1	2.239937 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-organic frozen	100 cal m-1 hr-1 celsius-1	6.978011 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-organic unfrozen	250 cal m-1 hr-1 celsius-1	17.44501 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-mineral frozen	900 cal m-1 hr-1 celsius-1	62.80197 Wm-1K-1			Farouki, 1981
Assumed Tundra soils-mineral unfrozen	770 cal m-1 hr-1 celsius-1	53.73056 Wm-1K-1			Farouki, 1981
Units		**Wm-1K-1**		**MJm-3K-1**	
Thawed		0.25		2.503	Peters-Lidard et al., 1997
Frozen		1.375		2.193	Peters-Lidard et al., 1997
To get frozen value I took the average of soil organics and ice					



DIRECT MEASUREMENTS WITH FLUX PLATES



RETRIEVED FLUXES WITH THEMISTOR STRINGS

Specialist: TurbulenceTerms
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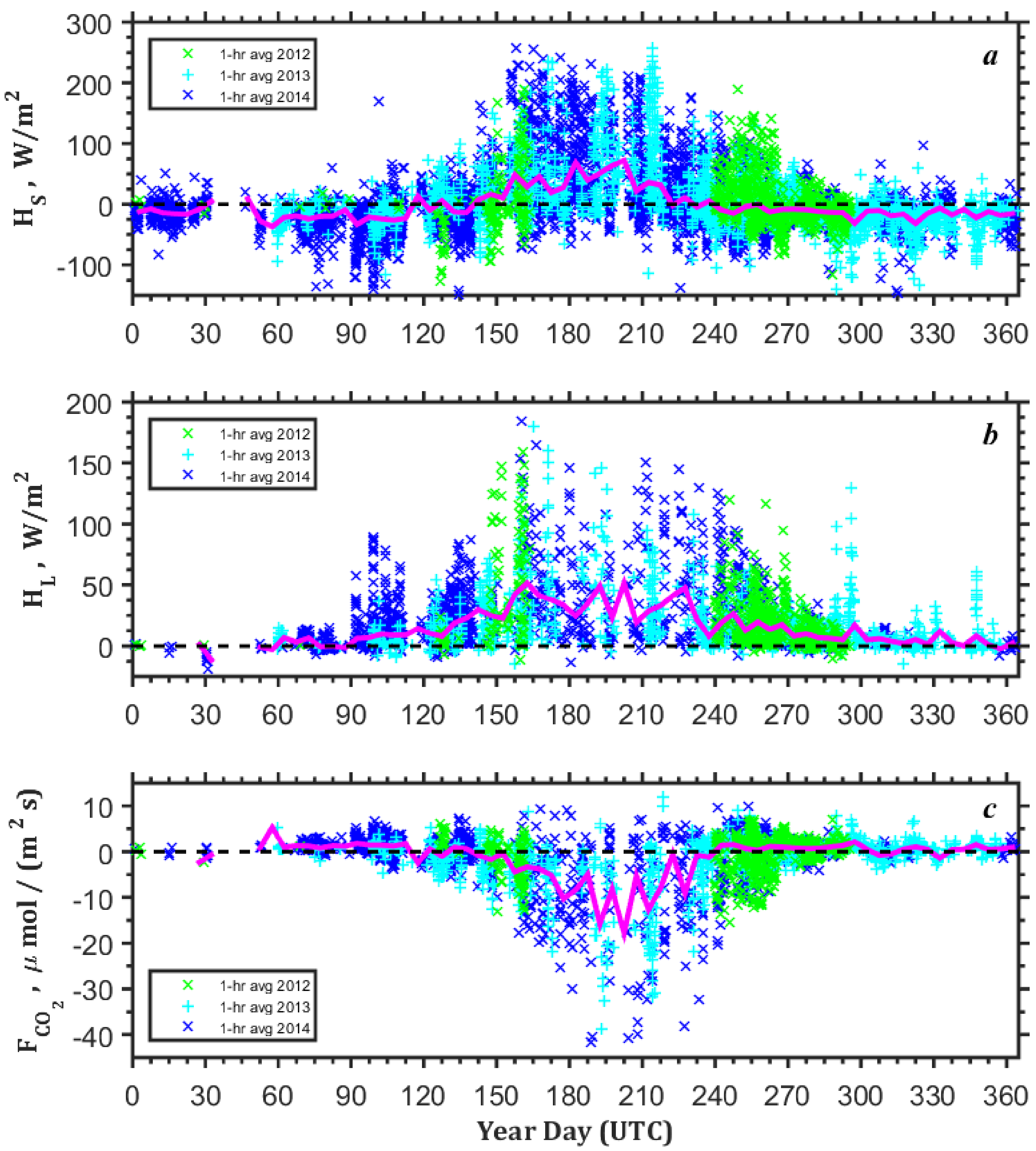
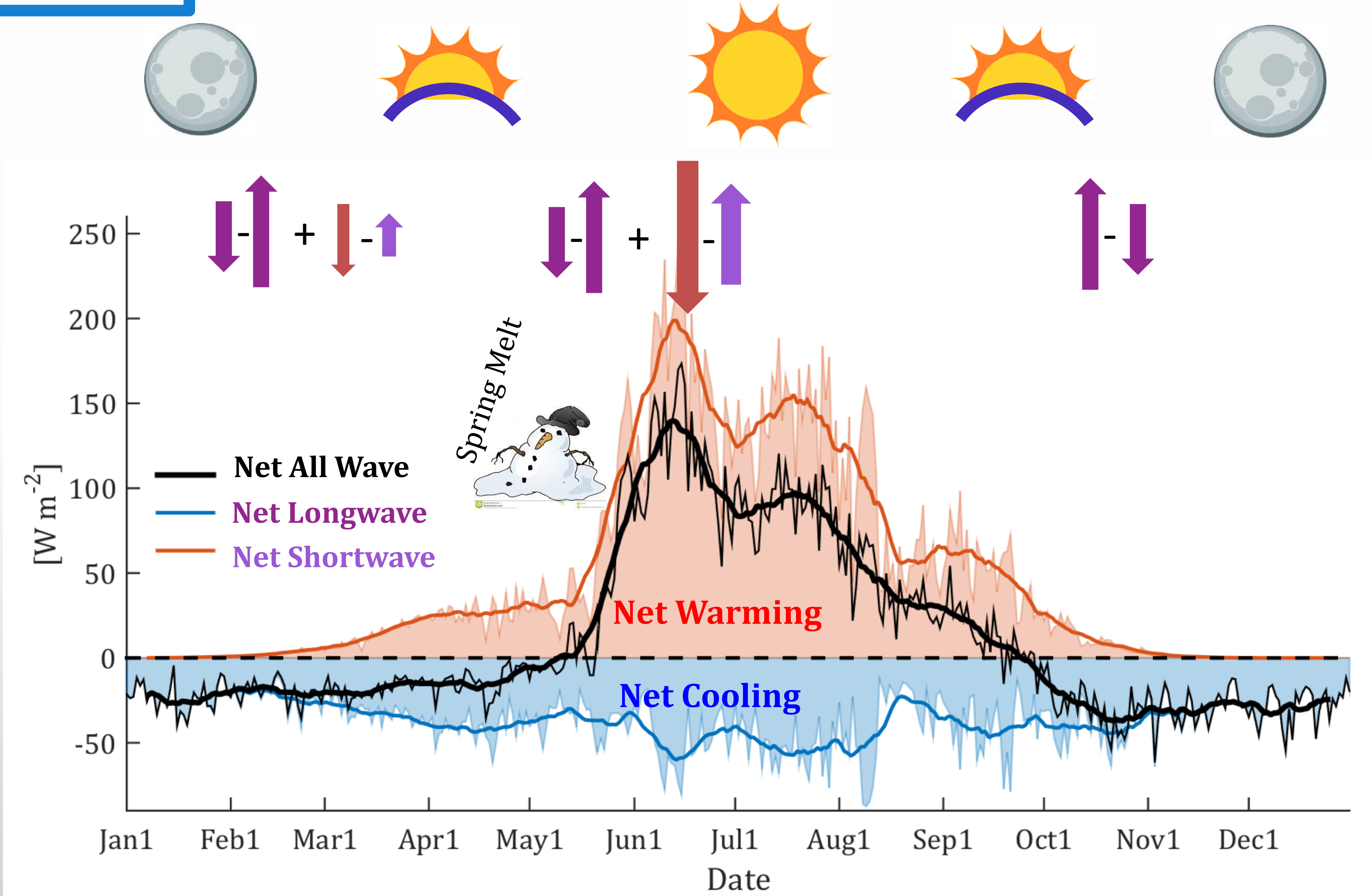
elena.a.konoplev@noaa.gov
ola.persson@noaa.gov



Specialist: Radiation Terms
christopher.j.cox@noaa.gov

Net Radiation Budget, Tiksi 2012-2014



SUMMARY

- Models without observations are video games

  Kathy Sullivan (Under Secretary of Commerce for Oceans & Atmosphere and NOAA Administrator)

  Town Hall Meeting in Boulder Colorado

- You only really measuring voltages and resistances therefore observations are just models

  Robin Webb (Director NOAA/Physical Science Division) when I quoted Kathy Sullivan to him in the hallway